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Reducing the Effective Slipperiness of Chemical-Biological Protective Shelter (CBPS) Flooring: Commercial Non-skid Shoe Covers and Alternative Materials

M. R. Fletcher

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Abstract

Teflon®-coated floorings (Chemlam-X22®[A] and X22[B]) of the chemical-biological protective shelter (CBPS) tent system are necessary for decontaminability but are slippery under foot. Under normal walking conditions, soldiers who wore ordinary combat boots reported a slipping hazard; under wet conditions with fast-paced movement, footing is expected to become even more precarious. Commercially available non-skid shoe covers were evaluated in the laboratory as a means of reducing the risk of slipping but did not prove to confer any non-slip advantage. Some alternate materials were identified that can be applied as tread to disposable shoe covers and would provide greater wet and dry slip resistance on the CBPS flooring than uncovered combat boot soles.

ACKNOWLEDGMENTS

I would like to thank Mr. Philip Brandler, Director of the U.S. Army Soldier Systems Center at the Soldier Biological and Chemical Command, Natick, Massachusetts, site, for supporting this study through the Continuous Product Improvement program. I would also like to thank those at Natick who assisted by supplying materials, equipment, and critical readings of the manuscript, and Dr. Edward Hirsch, Ergonomics Team Leader, who provided space and facilities for the work.

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REDUCING THE EFFECTIVE SLIPPERINESS OF CHEMICAL-BIOLOGICAL PROTECTIVE SHELTER (CBPS) FLOORING: COMMERCIAL NON-SKID SHOE COVERS AND ALTERNATIVE MATERIALS

1. Introduction

The chemical-biological protective shelter (CBPS) tent system, currently being developed, is intended as a battalion aid station to be used by Echelon I and II medical treatment teams. As such, it may be required to operate under chemical-biological warfare contaminated conditions and therefore must be cleanable and decontaminable. To this end, the Kevlar® fabric flooring is coated with Teflon®. The slipperiness of the Teflon®-coated flooring was identified as a safety hazard in early human use trials (Hanson & Drummond, 1992). Soldiers walking at ordinary speeds and under normal conditions on the material found it slippery. The likelihood is high that in actual use, the material would become wet with water or other fluids and become even more slippery. The rapid tempo of emergency medical work within the tent will exacerbate the hazard. In these circumstances, slip-and-fall accidents could result in compromised medical care and in additional injuries to medical personnel.

Because the flooring material must retain its resistance to chemical-biological agents and must retain its decontaminability, composition and texture changes of the material's surface are not an option. Attention therefore shifted to altering the properties of the footwear that will contact the floor. Modified combat boot soles or entirely new, dedicated footwear would not be cost effective to develop or convenient to employ, so disposable shoe covers that can be worn directly over any normal footwear appeared to be the best approach.

At an Integrated Process Team meeting at the Soldier Biological and Chemical Command (SBCCOM), Natick, Massachusetts, in July 1998, I volunteered to investigate increasing the coefficient of friction between footwear and the tent floor. Technical representatives of DuPont, the manufacturer of Teflon®, knew of no studies that addressed ways to maximize friction between Teflon® and other materials (D. Farelly, DuPont, personal communication, September 1998). In the spring of 2000, the Soldier Systems Center at Natick directed Continuous Product Improvement funding toward investigating the usability of existing commercial shoe covers with non-skid soles.

Disposable shoe covers used in hospitals and clean rooms generally consist of loose booties with elasticized tops that can be slipped easily over regular footwear. These items are available to cover the shoe only or to cover the entire

lower leg and are usually made of synthetic non-woven textiles of polypropylene, olefin, or polyethylene. To combat the slipperiness of these textiles on polished floors, manufacturers frequently offer one or more versions of non-skid shoe covers. The non-skid properties are obtained by (a) applying other, less slippery polymers as treads on the bottoms of the shoe covers by painting, dripping, or screen printing or (b) fabricating the soles of the shoe covers from materials embossed with a physical tread pattern.

Several different samples of non-skid shoe covers were acquired and evaluated against two versions of the CBPS flooring. For comparison purposes, later evaluation also included combat boot soles and some commercial and developmental sole materials and other products that might impart skid resistance.

2. Procedure

Two Teflon®-coated Kevlar® fabric materials were evaluated. The manufacturer designates the more flexible material as "Chemlam-X22," and the thicker, stiffer material is called "Chemlam–X22® floor"; in this study, they are termed A and B, respectively. Slip-resistance experiments using American Society for Testing Materials (ASTM) F 609 (ASTM, 1979; see Figure 1) were performed on commercially available non-skid shoe covers, combat boot sole materials, and other materials that might be applied to commercial shoe covers as non-skid treads. ASTM F 609 is generally not the test of choice today (English, 2001) since the equipment is no longer commercially available and the procedure is not specifically designed for use under wet conditions. In fact, there is currently no established standard for maximum floor slipperiness despite the fact that the Americans With Disabilities Act (U.S. Congress, 1991) suggests a coefficient of friction value of 0.5. Although the actual mechanisms of slip-and-fall accidents are much more complicated than this experiment suggests, ASTM F 609 was selected because it is a simple test that lends itself to preliminary materials screening, and it had already been used in earlier work with the CBPS system. Using the same test allowed comparisons among materials. The manufacturer's information included with the apparatus indicates that mean slip index (MSI) values of 6 or more are termed "relatively non-slippery," 5 to 6 as "generally acceptable," and 5 or less as "relatively slippery." The relationship of MSI values to coefficients of friction or established public standards is undefined.

Samples of bulk materials were cut from sheets or soles (0.25 to 0.375 inch thick) with a circular metal punch, resulting in plugs 0.5 inch in diameter. The plugs were then secured in the sample holders with rubber cement, and the sample holders were inserted into the apparatus (see Figure 2). Samples of shoe covers were cut from the tread portion of the item and attached to the bottoms of a

spare set of plugs with double-sided adhesive tape. The trials were all performed across or along the fabric, not on the bias, under both dry and water-wet conditions. The experiments consisted of measuring the slip resistance at 10 different locations on the flooring sample for each MSI value reported. The flooring was wiped clean between sets of measurements, and the slip meter was calibrated after every two or three sample sets. For the wet condition, approximately 50 ml of tap water were poured on the flooring and spread as well as possible, given the "unwettable" nature of the material. The sample materials mounted on the instrument were thoroughly wetted before wet measurements began, and the slip meter was positioned each time so that the feet contacted new wet areas of the flooring. The first set of trials (see Table 1) against the original flooring material (Chemlam-X22®[A]) included the shoe covers, older combat boot sole samples, and the material labeled "gasket". The second set of trials, with the newer flooring (Chemlam®-X22[B]), included the same samples as the first set plus new combat boot sole materials, commercial special application non-skid sole materials, and coatings applied to shoe cover textiles (see Table 2).

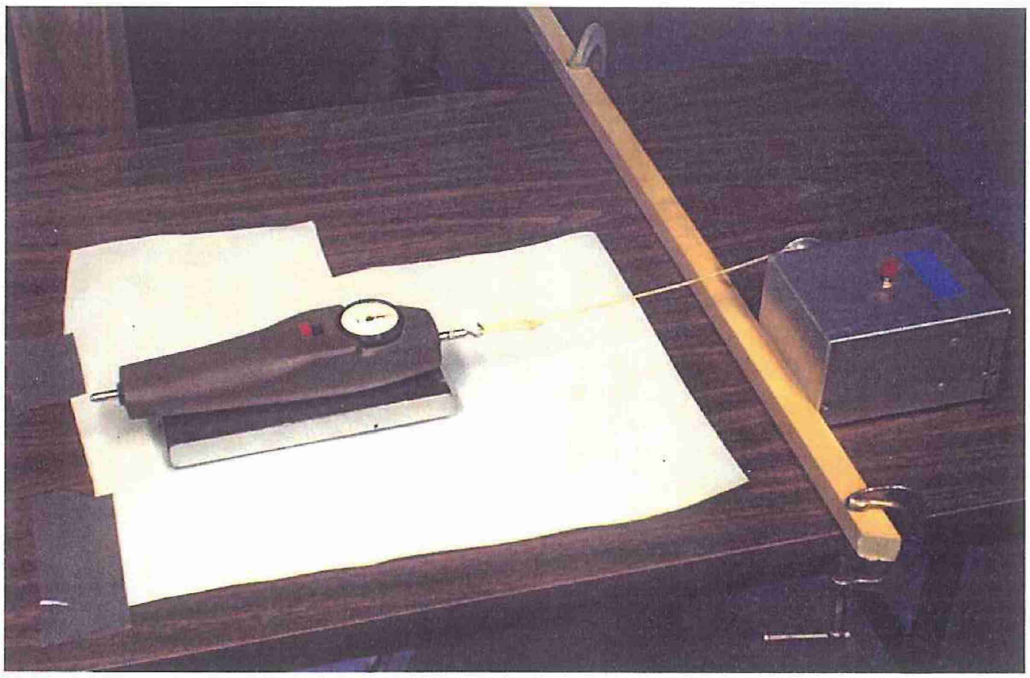

Figure 1. Apparatus and Setup for Measuring Slip Index.

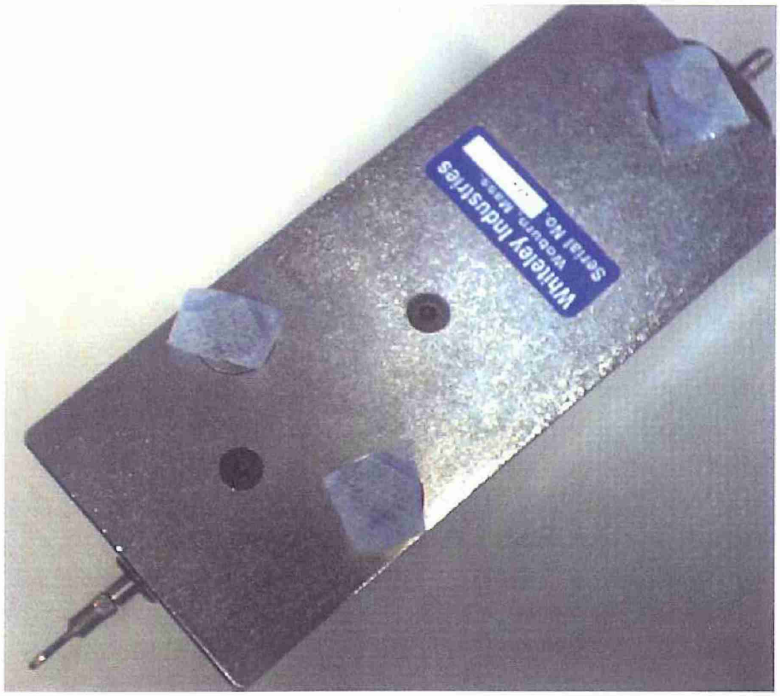

Figure 2. Apparatus With Specimens of Shoe Covers in Place on Rubber Feet.

Table 1. Materials Evaluated Against Chemlam-X22®(A)

Sample	Description	Source	Comments
091-4500	Shoe cover: Chevron-shaped white printed tread on blue non-woven textile	3S (Scientific, Supply Source)	"Non-skid"
1086WB	Shoe cover: 1- to 2-mm wide stripes of tread parallel to long axis of foot, 3 to 5 mm apart, on blue non-woven textile	Gepco (General Econopak), 1725 N. 6th St., Philadelphia PA 19122	
1184TGL	Shoe cover: Narrow closely spaced gray stripes on white non-woven textile	Gepco	"Anti-skid, fluid proof"
1286W	Shoe cover: two bands of clear slightly tacky tread "drizzled" on white non-woven textile	Gepco	
Gasket	Re-enterable splice case sealant (product # 125D)	General Sealants Inc., PO Box 3855, City of Industry CA 91744	
Old boot sole	Identified as "combat boot sole" in instrument set; used in previous evaluation	U.S. Army	Textured surface in contact with flooring

Table 2. Materials Evaluated Against Chemlam-X22®(B)

Sample	Description	Source	Comments
#344	Nitrile PVC combat-boot sole	Quabaug Corporation, 18 School St., N. Brookfield MA 01535	Conforms to U.S. Army CRF/PD 97-03B and 99-09
#3389	Styrene-butadiene rubber combat boot sole	Quabaug Corporation	Conforms to U.S. Army CRF/PD 97-03B and 99-09
TC-1	Styrene-butadiene rubber with natural rubber	Quabaug Corporation	Sticky to touch
"Grip"	Modified butyl rubber sole	Quabaug Corporation	
Matting	"Mighty Mat": One side scored rubber, other side embedded abrasive granules	Shoes For Crews, 1400 Centrepark Blvd., Suite 310, W. Palm Beach FL 33401	Compositions not available. $81 for 3-ft by 5-ft mat
SS-1	Skid-Safe® emulsion applied as coating on non-woven textile (three coats)	New Dimensions, 1551 37th Ave., San Francisco, CA 94122	"Highly slip resistant," water based
RC-1	Common rubber cement applied as coating on non-woven textile (three coats)	U.S. Army	

PVC = polyvinyl chloride CRFD[1] purchase description

3. Results

Table 3 and Figures 3 and 4 show that, in terms of this experiment, not only were the shoe covers no improvement over combat boot soles, but they generally resulted in increased slipperiness, wet or dry. The generally low MSI means and small standard deviations indicated that statistical methods were unnecessary to show that the shoe covers did not offer material improvement in slip resistance. All the actual sole materials investigated, as well as the gasketing and matting, performed better than the nominally skid-resistant shoe covers. The Skid-Safe® and rubber cement coatings did not perform well. In order to provide comparisons among materials, measurements on the high-performing materials are provided even though their magnitudes exceed 8, which is the maximum reliable reading from the slip meter. The useful limit of this method with the soft, tacky rubbers is related to the weight of the meter assembly as well as to the

[1] Not an acronym

coefficient of friction between the specimen and the flooring. At readings of about 9 or above on the slip meter, the trailing edge of the assembly begins to lift off the surface, and the materials being evaluated sometimes deform rather than actually slipping. The meter readings of these experiments did not show a clear point where slippage began but continued to rise even after the assembly began to move. With the gasketing, material smeared off the samples and remained on the flooring, although it did not bond tightly and could be removed by rubbing with a dry cloth. This gasketing, when left in contact with the flooring without moving, developed a tack that might result in problems in lifting the foot after one has stood still for long periods (see Figure 5). The shoe sole materials did not show this effect.

Table 3. Results of Experiments, This Study
(10 replications each)

Sample	MSI(dry)	SD (dry)	MSI (wet)	SD (wet)
	Against Chemlam-X22®(A)			
091-4500 (shoe cover)	2.5	0.4	2.1	0.2
1086WB (shoe cover)	3.5	0.3	3.5	0.1
1184TGL (shoe cover)	3.4	0.2	3.7	0.3
1286W (shoe cover)	5.1	0.3	4.4	0.4
Gasket	10.1	0.6	9.1	0.5
Old boot sole	5.0	0.2	4.2	0.1
	Against Chemlam-X22®(B)			
091-4500 (shoe cover)	2.6	0.2	2.3	0.3
1086WB (shoe cover)	2.5	0.3	2.3	0.3
1184TGL (shoe cover)	3.5	0.2	3.3	0.2
1286W (shoe cover)	3.2	0.2	3.4	0.2
Gasket	11.3	0.5	9.4	0.3
Old boot sole	5.0	0.3	5.1	0.2
#344 (nitrile PVC boot sole)	5.6	0.3	5.2	0.4
#3389 (styrene-butadiene boot sole)	6.5	0.2	8.4	0.3
TC-1 (styrene-butadiene+natural rubber)	7.4	0.4	10.8	0.3
"Grip" (modified butyl rubber)	9.5	0.5	9.4	0.3
Matting	5.3	0.3	5.1	0.3
SS-1 (Skid-Safe®)	1.8	0.1	1.7	0.1
RC-1 (rubber cement)	3.2	0.2	2.8	0.1

SD = Standard deviation

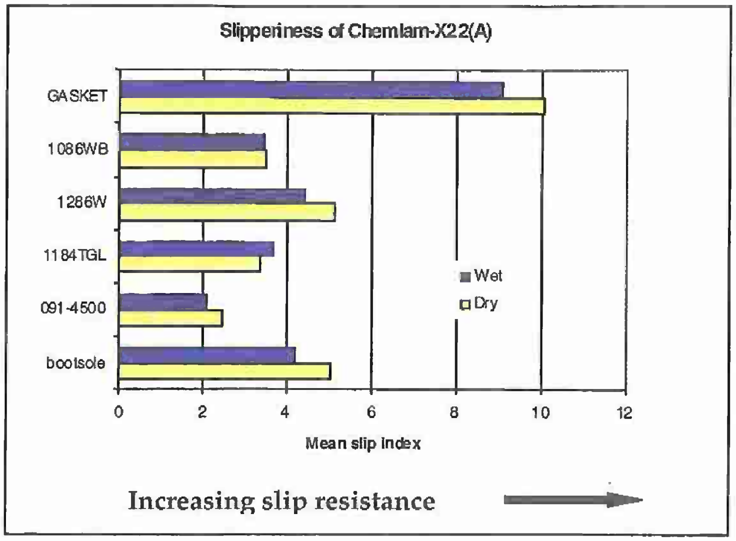

Figure 3. Slip Index Values for Shoe Covers, "Old Combat Boot Sole" and Gasket on Chemlam-X22®(A) (10 readings/mean value).

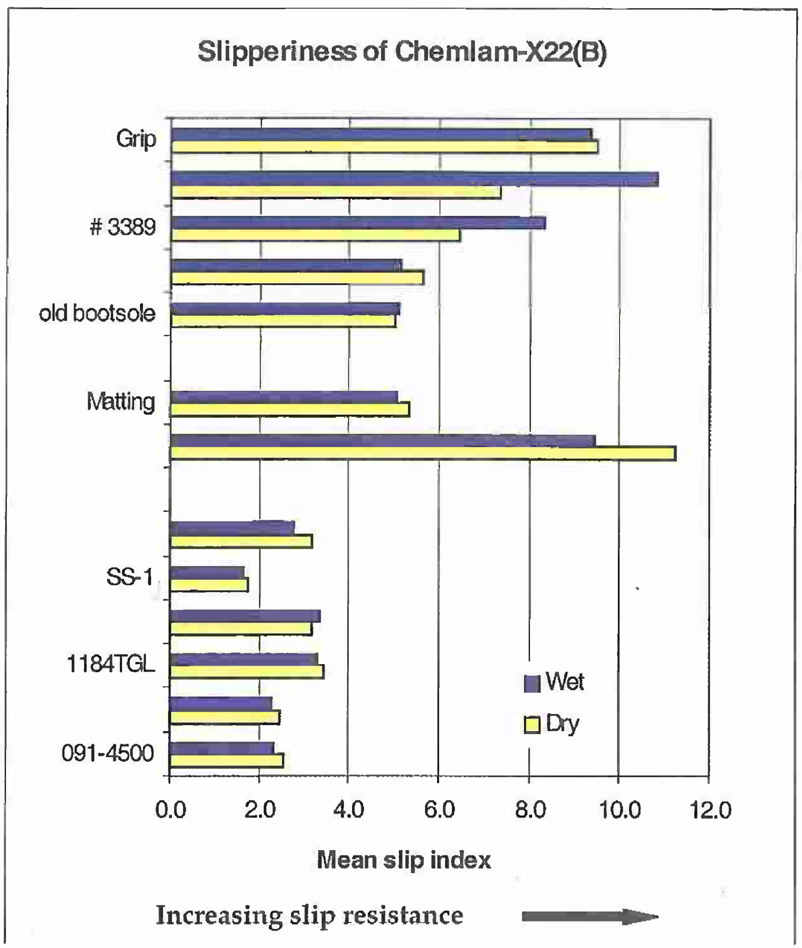

Figure 4. Slip Index Values for Shoe Covers, Boot Soles, and Other Materials on Chemlam-X22(B) (10 readings/mean value).

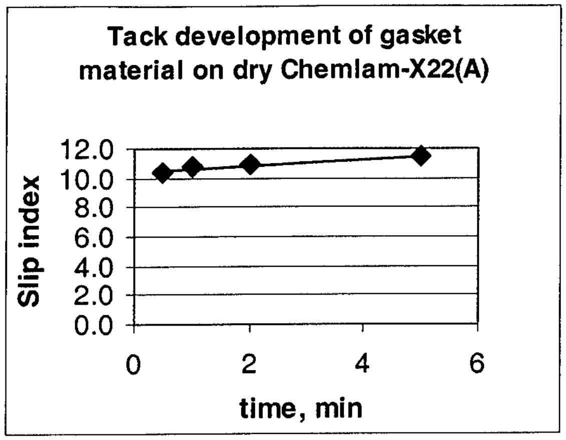

Figure 5. Slip Index Increase With Increasing Static Contact Time, Gasket on Chemlam-X22®(A).

4. Discussion

The insurance and safety industries have long been interested in preventing slip-and-fall accidents (Brungraber, 1976), and research into flooring and shoe sole materials as well as the mechanics of evaluation are ongoing (Manning & Jones, 2001; Gronqvist & Hirvonen, 1999; Chang, 1999). The safety of pedestrians in public areas and of industrial workers where the footing may be contaminated with water or oil, forms the major thrust of most of this work because of the economics of law suits and workers' compensation and lost productivity costs. Thus, no investigations into slipping on Teflon®-coated surfaces exist because in the normal course of events, no one would consider using it as flooring.

Earlier tests of the "old combat boot sole" against Chemlam-X22®(A) (P. Stewardson, SBCCOM, personal communication, January 1999) gave slip indices of 3.0 to 5.25 (six individual measurements). These numbers are in line with those found in the current study. However, one of the newer combat boot sole materials obtained from the manufacturer gave higher MSIs for both dry and wet conditions. This suggests that some existing combat boots would provide better traction on the CBPS floor than would others. If it can be determined that boots with certain sole materials provide better slip resistance, it might be worthwhile to ensure that these boots are issued to medical and support personnel assigned to work with the CBPS system.

During the course of this study, materials have been identified that may produce a good non-skid contact with the Chemlam® floorings if they are applied to shoe covers as tread. Some of the more promising materials are discussed at length in the following section. In addition, a non-slip anti-fatigue matting was investigated.

4.1 Gasket

The material termed "gasket" is a black, soft, tacky surfaced material designed for sealing electrical splice boxes and is supplied in tape, cord, and sheet forms. It was first encountered during an ensuing test and evaluation of the Chemically Protected Deployable Medical System disc-clamp seal at the Regional Training Site-Medical (formerly Ft. Devens) in Ayer, Massachusetts, in August 1998 (Woods, 1998), where its tendency to stick to the tentage material suggested that it might prove useful in the present study. The gaskets were supplied as pre-cut disks about 3 inches in diameter and 0.25 inch thick. A new disk was the source of the material used in the present study. The excellent performance of this material in slip experiments prompted discussion with the manufacturer, who termed it a "partially cured polyethylene synthetic rubber" (D. Carringer, General Sealants, personal communication, March 1999). No further information was given about its composition. Because the material was quite tacky in contact with the Chemlam® floorings, the possibility exists that too much adhesion would develop if a large area of the gasketing remained in contact with the flooring for any length of time, and a full sole made of the gasketing would probably not be suitable. When the manufacturer was approached about the possibility of modifying the composition or production methods to allow a pattern of small nubs or dots to be printed on disposable non-woven material that could then be made into shoe covers, he expressed no interest in investigating the material for this application, given its supposed small profit margin. However, a good skid-proof sole for disposable shoe covers might find a very wide market, since discussions with manufacturers of the commercial varieties and with medical and dental personnel revealed that the current offerings are considered to have unsatisfactory slip resistance.

4.2 Commercial Soling Materials

Commercial polymeric and rubber shoe sole compositions, including those for combat boots, are frequently designed with wear resistance in mind; tread patterns provide slip resistance. Between otherwise identical shoe soles, differences in small-scale roughness (about 3 to 60 μm resin transfer molded), "stickiness" (tack), and backing rigidity may control slip resistance on water-wet surfaces, as shown in an extensive study of commercial soling materials (Manning & Jones, 2001). In that study, the soles with the highest measured surface roughness generally showed the highest slip resistance when studied in contact with water-wet surfaces. The best performer overall, however, was a rock-climbing boot sole, with a shear strength so low that it smeared during polishing. The rather sticky rubbers used in the soles of climbing boots may have properties similar to those of the gasket material evaluated in this study. While such materials are not particularly durable, this is not a problem with disposable shoe covers.

Army combat boots are subject to performance specifications rather than materials requirements (T. Meehan [Defense Supply Center, Philadelphia],

personal communication; June 2001). The specifications address abrasion and tear resistance, chemical resistance to fuel oils, and tendency to rub off on or "mark" floors; none of the performance specifications address the coefficient of friction (e.g., U.S. Army, 2000a and 2000b). Quabaug manufactures two common combat boot out-sole materials currently in use and considered in this study: a nitrile polyvinyl chloride (PVC) and a styrene-butadiene rubber (corresponding to compounds 344 and 3389 made by Quabaug-Vibram; T. Miner, personal communication, June 2001), selected largely for wear resistance. Quabaug also manufactures the two materials used in rock-climbing footwear that are evaluated in this study: a butyl rubber ("Grip") and a styrene-butadiene-based compound that contains natural rubber as well (TC-1). The butyl rubber provided the highest dry MSI of any of the actual sole materials evaluated in this study, exceeded only by that of the gasket material. However, the compound containing natural rubber provided the highest wet MSI of any material evaluated in this work.

4.3 Custom Materials

Many commercially available polymers are used in the manufacture of materials for specific applications, including shoe soles, and much of the following information no doubt applies to several manufacturers. As an example, Kraton®, a series of polymers manufactured by Polymers Incorporated (formerly Shell Chemicals), possesses highly tailorable properties in terms of strength, deformation, and tack. Some of the Kraton® formulations possess better wet traction than the PVC rubbers commonly used for footwear soles (D. St. Clair, Polymers, Inc., personal communication, June 2001).

Depending on specific compositions, most of these polymers can be processed as "hot melts" or solvent-based solutions via extrusion, coating, or injection molding. Liquid formulations can be screen printed or painted onto a fabric backing; hot melts can be extruded through a pattern of nozzles to make a discontinuous tread. While the solvent-based approach is probably easier in terms of manufacturing equipment, the necessary solvents (e.g., toluene, heptane, hexane, isopropyl acetate) are hazardous and would result in safety and disposal or recycling considerations. The cost effectiveness of the two processing methods is competitive. The Kraton® polymers and additives themselves currently cost from $1.00 to $2.50 per pound, which is in the price range of other commonly used polymeric shoe sole materials.

4.4 Matting

"Shoes for Crews," a company specializing in industrial footwear, manufactures the non-slip matting evaluated in this study. The matting consists of a 0.375-inch thick layer of black rubber (unidentified), which is scored at intervals of approximately 0.375 inch on one side and covered with coarse abrasive granules (unidentified; probably silicon carbide) on the other. The abrasive side clearly

could not be used in contact with the CBPS floor, so evaluation was done on the rubber side. Product literature indicates that the rubber used in the matting is the same compound that is used in the company's shoe soles.

4.5 Other Materials

Skid-Safe® is a water-based paint-type floor coating containing acrylic copolymers, butoxyethanol, and ethylene glycol. While it is designed for essentially rigid flooring materials, product literature recommends it for use on flexible rubber flooring as well. A sample was obtained and three coats were applied to non-woven shoe cover material (obtained from parts of commercial shoe covers – sample SS-1). Similar samples were made by the application of three coats of common rubber cement to the same textile, as an example of a polymeric coating readily and cheaply available (Sample RC-1). Results obtained from these materials do not warrant further investigation here.

4.6 Shoe Covers for the CBPS

A small, discontinuous tread pattern of dots or lines that protrudes from the surface of the shoe cover provides better traction on water-wet flooring than does a continuous sole surface, because the nubs will penetrate the water film rather than just push it ahead of the descending foot. Pushing the liquid forward uniformly could result in hydroplaning and a slip accident. Thus, the challenge is to find materials with acceptable traction properties combined with suitable processing requirements that can be applied to shoe cover textiles.

Without our recommending any particular product, the results obtained in this study indicate that materials do exist that are effective and processable in the manufacture of shoe covers with high traction in contact with the CBPS flooring; that is, they lend themselves to screen printing or extrusion patterning onto the non-woven synthetic fabrics normally used in shoe covers. The gasket material, TC-1, and "Grip" all performed markedly better in at least one condition (wet or dry) than any of the combat boot soles evaluated. While the gasket manufacturer did not feel that his material was suitable for application to textiles, the other materials probably can be adapted to such processing (T. Miner, Quabaug Corp., personal communication, June 2001), which suggests that similar materials would be generally useful in shoe cover fabrication.

Because no single material proved superior to others in both wet and dry conditions, two different materials can be combined, as shown in Figure 6. Such an approach, using two separate operations to lay the tread pattern, would accommodate even materials that are chemically incompatible and would provide the cross-sectional tread profile desirable on water-wet surfaces. The materials evaluated cost about $1.00 per pound, and therefore, this approach would be competitive with custom-developed polymers.

5. Conclusions

The commercial shoe covers investigated are unsatisfactory for slipperiness reduction in the CBPS system, since none of them demonstrate any improvement over the combat boot sole. Some of the alternate materials evaluated performed well under wet and dry conditions, and some of these high performers are amenable to processing as tread on disposable shoe covers. Custom shoe covers could be made that incorporate the materials that demonstrably reduce slipping during anticipated use conditions, or disposable non-slip mats might be considered.

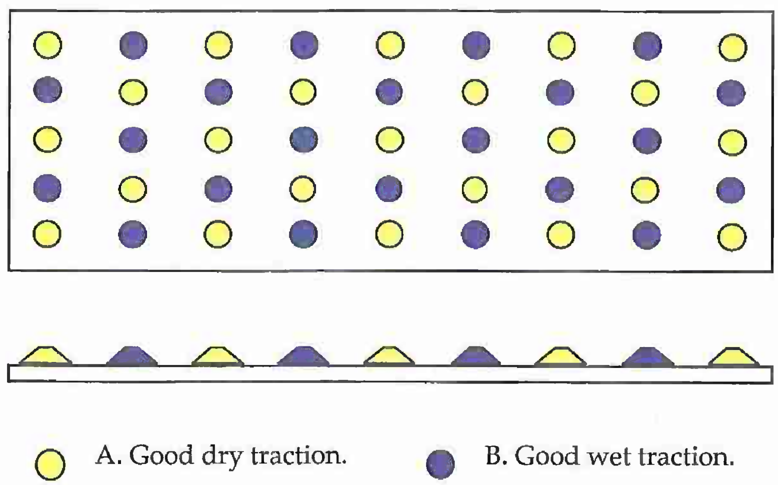

Figure 6. Proposed Pattern for Combining Different Materials on Shoe Cover Textile to Provide Tread for Both Wet and Dry Traction on Chemlam® Flooring (plan view and cross section).

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13. ABSTRACT *(Maximum 200 words)*

Teflon®-coated floorings (Chemlam-X22®[A] and X22[B]) of the chemical-biological protective shelter (CBPS) tent system are necessary for decontaminability but are slippery under foot. Under normal walking conditions, soldiers who wore ordinary combat boots reported a slipping hazard; under wet conditions with fast-paced movement, footing is expected to become even more precarious. Commercially available non-skid shoe covers were evaluated in the laboratory as a means of reducing the risk of slipping but did not prove to confer any non-slip advantage. Some alternate materials were identified that can be applied as tread to disposable shoe covers and would provide greater wet and dry slip resistance on the CBPS flooring than uncovered combat boot soles.

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